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EDGERTON, GERMESHAUSEN & GRIER, INC.

PHOTOGRAPHIC MEASUREMENTS ON BANSHEE
SUPPLEMENT NO. 1 - 1962 EVENTS

Lt. Col. C.C. Clifford, USA, Project Officer

Authors:
James C. McCue
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Edgerton, Germeshausen & Grier, Inc.
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EG&G Report No. B-2602
DASA Report No. DASA-1393-1
CONTRACT NO. DA49-146-XZ 092

This work was accomplished under NWER Subtask 01.001 for the Defense Atomic Support Agency, Washington 25, D.C.

BOSTON AND SALEM, MASSACHUSETTS
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ABSTRACT

During the summer of 1962 several Phase I and Phase II BANSHEE events were scheduled at White Sands Missile Range in an attempt to conclude these phases of the operation. Unavoidable weather conditions prevented any Phase II events (missile-borne charge, instrumented balloon) from being completed, but five Phase I events (charge and instrumentation canisters on balloon dragline) were accomplished. Of these, three were successfully covered by fireball photography. The altitudes of these three events were 103,726 feet (B-20), 103,370 feet (B-20A), and 81,258 feet (B-24A).

Data reduction and analysis were performed along the lines established in the earlier report. Radius versus time plots of the 1962 data indicate, as would be expected, a more rapid expansion rate of the fireball at early-times. Reduced radius (λ) versus reduced time (τ) plots are found to be in fair agreement with the scaled data from earlier events for τ values up to 0.2 feet atmospheres$^{1/3}$ pounds$^{-1/3}$. Beyond this τ value, the higher altitude data produce larger λ values, and do not exhibit the gradual tapering-off observed for the earlier events.

CONTENTS

CONTENTS (Continued)

CHAPTER 1

INTRODUCTION AND BACKGROUND

1.1 INTRODUCTION

This report covers the 1962 BANSHEE events, and presents photographic data obtained during that period. It is a supplement to the previous report, Reference 1, which covered the 1961 BANSHEE events. Details regarding the overall BANSHEE photographic measurements program may be found in the previous report.

This project again, was a joint tri-service operation; the U. S. Naval Ordnance Laboratory (NOL) was responsible for design and development of the electronic instrumentation system and the firing circuit; the Ballistic Research Laboratories (BRL) were responsible for design of the high explosive charge, the self-recording mechanical instrumentation system, and surface pressure measurements; and the Air Force Cambridge Research Laboratories (AFCRL) were responsible for providing the necessary techniques, personnel, equipment, and facilities to satisfy the high altitude balloon and command-control requirements.

The principal photographic objectives to be achieved on these high altitude detonations were the measurements of the rate of fireball growth, documentary coverage, and location of the burst coordinates. The early stages of fireball growth give information of importance to the problems of explosion hydrodynamics. It is to this early time region that this report will restrict itself. The intermediate and late time stages, while also photographed in detail, yield little information specific to the hydrodynamics phenomena of interest to other project agencies participating in BANSHEE.

Tracking telescopic cameras and the personnel for aiming them were furnished by the White Sands Missile Range (WSMR) as part of their normal support for such projects as BANSHEE. EG&G personnel assumed responsibility for the planning and liaison of the photographic effort as well as the film sensitometry and the data reduction and analysis.

1.2 BACKGROUND

Project BANSHEE, as established by the Defense Atomic Support Agency (DASA), was a research program for the investigation of explosion hydrodynamics at high altitudes. The name BANSHEE is an acronym for Balloon and Nike Scaled High Explosives Experiments. Detonations were planned at altitudes ranging from 38,000 feet to 115,000 feet and were scheduled for the summer of 1961 at White Sands Missile Range (WSMR). The explosives were 500 lb spherical charges of pentolite. The program was intended to be carried out in two phases; the first phase utilized large polyethylene balloons to carry the high explosive charges and blast instrumentation to the altitudes of interest, and in the second phase, Nike-Hercules missiles were to be used to carry the HE charge while the instrumentation was still to be carried by balloons.

Late in the planning stage of BANSHEE Phase I, the DASA program was broadened to cover the electromagnetic (EM) phenomena associated with the detonation of high explosives. The original EG&G effort on BANSHEE was intended primarily to measure EM signals at a ground station and to correlate these signals with fireball size using a telescopic camera. Later, the EG&G program was expanded to include the responsibility for coordinating the complete fireball photography for BANSHEE.

Because of unpredictable winds and the problems of launching a balloon with an explosive burden, the program suffered a number of setbacks during the 1961 operation. By the time winter weather forced a closing of the operation, only a part of the scheduled two phases of the program had been carried out.

Of the ten shots originally scheduled for Phase I, only four were achieved in 1961. Of the seven shots scheduled for Phase II, only one was completed in 1961. The 1962 operation was intended to complete both the Phase I and Phase II programs.

CHAPTER 2

PROCEDURE

2.1 INSTRUMENTATION

On the average, photographic coverage of the BANSHEE events was again provided by five IGOR telescopes equipped with 35mm Photo-Sonics Type 4C cameras. These cameras provided continuous growth data with a time resolution (on the order of two microseconds) much superior to the conventional framing cameras whose interframe time resolution was about 360 microseconds. White Sands Missile Range provided cine-theodolite coverage for location of burst positions with respect to camera stations.

Centering of the indistinguishable HE charge in the camera frame was accomplished by tracking the balloon through twenty-power finding scopes.

2.2 CAMERA ORIENTATION AND POSITIONS

Difficulty in predicting burst locations, particularly at the high altitudes planned for the 1962 operation, necessitated wide dispersion of camera stations. The stations employed are tabulated in Table 2.1, with their geographic locations given in WSCS coordinates.

Figure 2.1 is a map which defines the WSCS and locates the camera positions used in photographing the events. Coordinates of the burst locations for both the 1961 and 1962 events are also shown in the figure.

2.3 BANSHEE IN-FLIGHT CONFIGURATION

The spherical 500 lb pentolite charge was suspended in a nylon harness approximately 200 feet beneath the balloon and was center-point detonated upon

telemetry command. Blast-line instrumentation was returned intact to earth via parachute.

2.4 PHOTOGRAPHIC RECORDING

The combination of IGOR telescope and Photo-Sonics 4C camera was again employed almost exclusively, but additional magnification was attempted during two events by using the 175-inch and 192-inch Barlow telescopic lens systems at one station. The operating characteristics of the cameras and telescopes for the 1962 operation are tabulated in Table 2. 2. The image resolution of 20 lines/mm is a nominal figure based on estimates of atmospheric distortion effects.

Timing markers were applied to the photographic records from the WSMR G-1 coded signal. This is a one-half millisecond pulse occurring at one millisecond intervals. On the framing camera records, zero time is indeterminate to within the interframe time since it can occur at any instant between shutter closure or complete exposure. The streak camera, which is continuous in its exposure, records the image at zero time, and is accurate to within the resolution limitations of the overall system. For streak cameras operating at 100 feet per second, the time resolution is approximately two microseconds (assuming an image resolution of 20 lines per millimeter).

Table 2.1 WSCS Coordinates Of BANSHEE Camera Stations

Station Designation	East (feet)	North (feet)	Altitude (feet)
T-9	509,381.36	322,241.96	3,229.17
T-12	497,878.10	371,182.53	3,706.53
T-15	460,390.26	490,697.73	3,985.23
T-163	522,766.28	572,227.92	4,080.67
T-169	515,746.79	489,908.63	3,995.38
T-197	470,458.78	323,165.54	3,392.41
T-199	450,098.41	427,481.28	3,834.55

Table 2.2 Camera And Telescope Fixed Operating Characteristics

Camera Type	Range Location (See Fig. 2.1)	Focal Length (feet)	Format (mm)	Image Resolution (lines/mm)	f/n
Slitless Streak (Modified Photo-Sonics 4C)	T-9	8	25.4 x 17.5	20	6.0
Photo-Sonics 4C	T-12	8	25.4 x 17.5	20	6.0
Photo-Sonics 4C	T-15	16	25.4 x 17.5	20	12.0
Photo-Sonics 4B	T-163	8	25.4 x 17.5	20	6.0
Mitchell	T-169	8	25.4 x 19.0	20	6.0
Photo-Sonics 4B	T-197	14.6	25.4 x 17.5	20	10.9
Photo-Sonics 4B	T-199	8	25.4 x 17.5	20	6.0
Mitchell	T-15	8	25.4 x 19.0	20	6.0

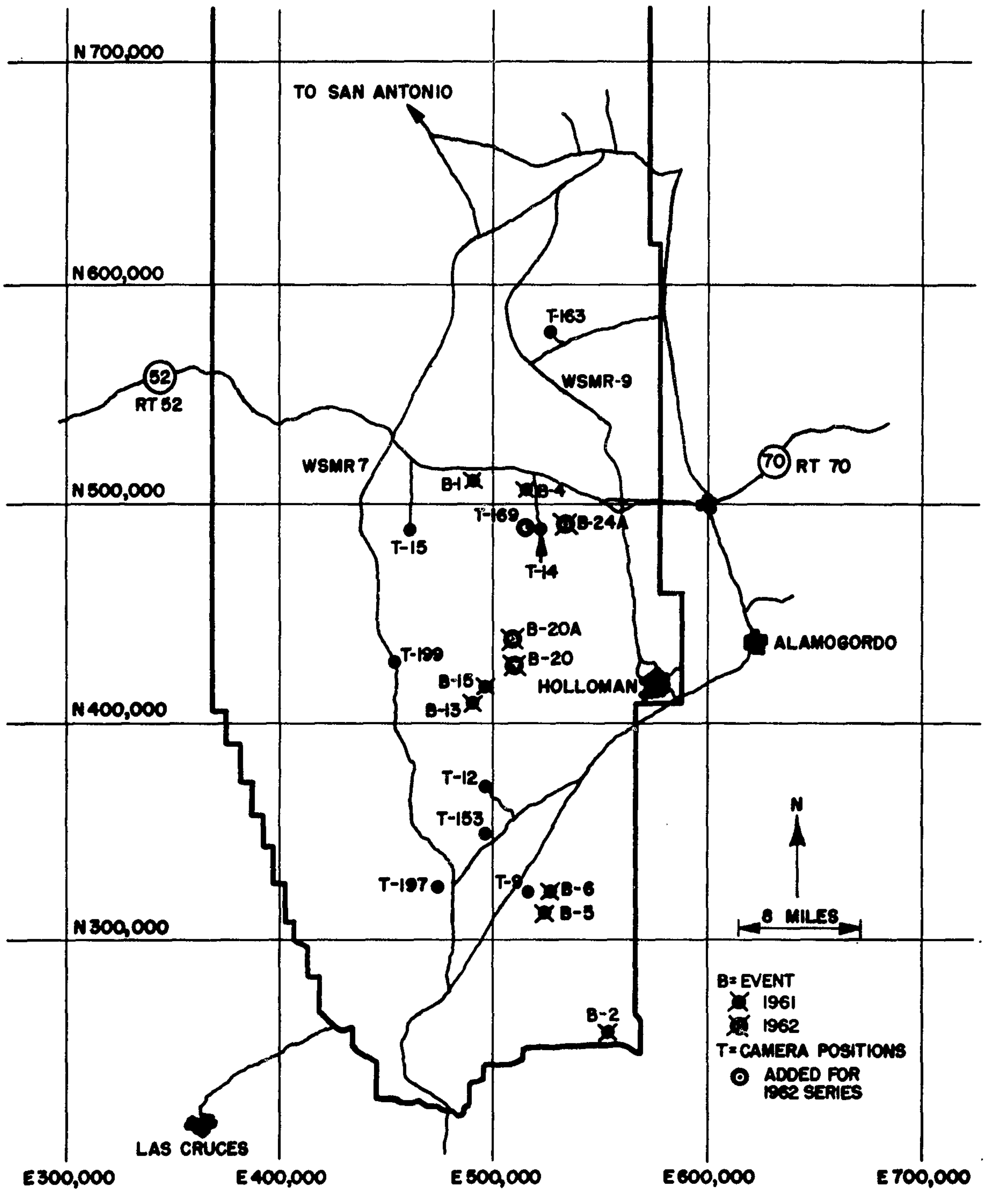


Figure 2.1 White Sands Missile Range, 1961 and 1962 BANSHEE Camera Stations And Events Indicated

CHAPTER 3

RESULTS

3.1 GENERAL

The "live" events and the success in photographic coverage for the 1962 operation were as follows:

Phase I Events

A. Detonation with successful fireball photographic coverage:

B-20	27 July
B-20A	10 August
B-24A	17 August (limited data due to late detonation)

B. Detonation without successful fireball photographic coverage:

B-21	23 July (film exhausted due to late detonation)
B-21	6 September (balloon drifted out of range)

Phase II Events

None launched

Once again, poor weather conditions (mostly winds of unfavorable speed and/or direction) accounted for many postponements and cancellations of events. Balloon leakage or bursting also contributed to the considerable delays. Improper balloon position (due to drift) and difficult balloon launching because of high winds, were the causes for the lack of Phase II events.

Complete fireball photography was obtained for two Phase I events B-20 and B-20A. The Barlow telescopic optics did not yield satisfactory resolution and

were abandoned on subsequent events. Limited data was obtained for the B-24A event because of film run-out before a late detonation. Attempts to delay the repeat count-down by five minutes to permit camera reload were not successful. This happened on one other occasion (B-21 detonation of 23 July) with the result that no fireball data was obtained.

The limited data from B-24A was obtained with two slow speed Mitchell cameras. These cameras were running as last minute replacements for two inoperative Photo-Sonics. It was a strange but gratifying coincidence that these slow cameras alone obtained data, however limited. A commendable attempt was made by the USMR operator at station T-12 to reload his Photo-Sonics 4C Camera before the second detonation attempt. Insufficient delay, however, prevented coverage of the fireball phenomenomenology. This station did obtain late cloud and parachute descent coverage in color.

3.2 BURST POSITIONS AND SLANT RANGES TO BURST

The three live events, whose fireballs were photographed successfully, are indicated in Figure 2.1 as B-20, B-20A, and B-24A, and their air-zero locations are tabulated in Table 3.1. The geometric parameters, defining each event for the various camera stations employed, are presented in Table 3.2. These parameters were obtained from WSMR data reduction of photo theodolite records, and by EG&G computation of the corresponding slant range distances. The columns designated ΔZ, ΔE, and ΔN are the distances in the vertical, easterly, and northerly directions respectively, from detonation air zero to the camera station concerned. The WSTM coordinate system has been employed for the 1962 operations, since corrections for earth curvature are minimized in this system.

3.3 CHARACTERISTICS OF THE DATA RECORDING SYSTEM

Tables 3.3 and 3.4 summarize the pertinent instrumentation and film characteristics, established to date, for BANSHEE events B-20, B-20A, and B-24A.

Table 3.3 tabulates the instrumentation characteristics, for each event, at every camera station. The magnification is defined as the ratio of IGOR system focal length to slant range of event, tabulated in Table 3.2. This is presented in Table 3.3 as the reciprocal of magnification since this is the multiplication factor employed to convert image dimensions on film to object dimensions in space. Field-of-view is that area in space, at the given slant range, which is encompassed by the format of the camera. The dimensions of this rectangular field are computed from the magnification and camera format values (25.4 mm x 17.45 mm for the Photo-Sonic cameras) pertaining to the station concerned. The field-of-view is presented as the dimensions, in feet, of this spatial area at the object.

The frame rates are nominal values selected by the drive motor control. A frame rate is subject to variations in film speed during start-up and while at "steady-state" operation. The actual film speed measured during data reduction is presented in Table 3.4. The column designated Shutter Opening is the sector angle of the rotary shutter. Thus, for a value of 72°, the exposure time is reduced by the fraction $\frac{72}{360}$, where 360° is a 100% shutter opening which yields an exposure determined only by the framing rate. The nominal exposure time is determined from the nominal frame rate and shutter sector angle, or shutter opening. This is calculated from the following expression:

$$\frac{\text{Exposure time}}{\text{(seconds)}} = \frac{\text{Shutter opening (degrees)}}{360} \times \frac{1}{\text{frames/second}}$$

The last column of Table 3. 3 is the ND (Neutral Density) value of the filter, if any, used during the photographing of the event.

Table 3. 4 presents the major characteristics of the film containing the recorded data, and is self-explanatory for the most part. The measured film speed column is given in frames/second, except for the streak records where millimeters/microsecond is more meaningful. The remarks column contains miscellaneous information from a subjective evaluation of the record made during data reduction and/or review.

3. 4 PHOTOGRAPHIC RECORDS

Typical photographic records for the 1962 series of events are reproduced in Figures 3. 2A and 3. 2B. Figures 3. 1 and 3. 3 are streak recordings (actual size) from events B-20 and B-20A. Approximately 11 msec of the streak records are shown. Figure 3. 2 consists of selected frames from the B-20A event, station T-12.

One interesting phenomenon observable in this framing series (Figure 3. 2) is the occurrence of a late-time rebrightening of the fireball, shown in frames 9 through 11. This is observable on most of the recordings, but is particularly noticeable on the color records.

3. 5 DATA REDUCTION

Fireball radius versus time data from the three events B-20, B-20A, and B-24A were obtained by visual measurement on a Hauser comparator. Data from eight camera records are presented as log-log plots in Figures

3.4 through 3.11. Both slitless streak and framing camera data are presented for B-20 and B-20A, while B-24A data are from one slow-speed framing camera only. Figure 3.12 is an intercomparison of the three events on a linear basis using streak camera records where available.

Examination of the streak camera data (Figures 3.4 and 3.8) indicates that the behavior of the expansion of the fireball at these altitudes is similar to that at the lower altitudes investigated in the original report. The expansion rate is faster, however, as would be anticipated at the lower ambient pressure encountered. This can readily be seen in Figures 3.13 and 3.14, where the 1961 and 1962 radius vs time data are plotted for comparison purposes.

Table 3.1. Air Zero Coordinates (WSTM) Of Live Events With Successful Fireball Photography

Event	X (E)	Y (N)	H (Z)
B-20	508,668	358,528	103,726
B-20A	508,399	371,623	103,370
B-24A	534,352	442,085	81,258

Table 3. 2 Geometric Parameters For 1962 BANSHEE Events

Event	Camera Location	ΔH (Z) (feet)	ΔX (E) (feet)	ΔY (N) (feet)	Slant Range (feet)
B-20	T-9 (Streak)	99, 737	711	102, 751	143, 200
	T-12	99, 621	10, 789	53, 819	113, 742
	T-15	99, 700	48, 269	65, 670	128, 773
	T-169	100, 722	7, 075	64, 881	120, 019
	T-199	99, 706	58, 559	2, 467	115, 657
B-20A	T-9 (Streak)	99, 381	980	115, 846	152, 636
	T-12	99, 265	10, 520	66, 914	120, 174
	T-15	99, 345	48, 000	52, 575	122, 219
	T-163	99, 152	14, 362	134, 087	167, 382
	T-197	99, 207	37, 934	114, 921	156, 486
	T-199	99, 350	58, 290	10, 628	115, 677
B-24A	T-12	77, 853	36, 473	137, 376	No Fireball Image
	T-15	77, 233	73, 953	17, 887	108, 415
	T-169	77, 254	18, 609	18, 675	81, 629

Table 3. 3 Instrumentation Characteristics

Event	Camera Station	(Magnification)$^{-1}$ X 10^{-3}	Field Of View (feet)	Nominal Frame Rate (frames/sec)	Shutter Opening (Degrees)	Nominal Exposure Time (msec)	Filter (N.D.)
B-20	T-9 (Streak)	17.900	1492 x 1025	2,500	360	0.40	0.3
	T-12	14.218	1092 x 750	1,500	72	0.133	No
	T-15	8.048	1329 x 913	1,250	72	0.160	No
	T-169	15.002	1250 x 860	75	72	2.67	No
	T-190	14.457	1145 x 787	1,500	72	0.133	No
B-20A	T-9 (Streak)	19.080	1590 x 1092	2,500	360	0.40	0.3
	T-12	15.022	789 x 542	2,000	72	0.10	No
	T-15	7.639	637 x 438	1,250	72	0.160	No
	T-163	20.923	1667 x 1145	2,500	72	0.08	No
	T-197	10.718	893 x 614	1,500	72	0.133	No
	T-199	14.460	1184 x 813	1,500	72	0.133	No
B-24A	T-12	No Fireball Image		1,000	72	4.0	No
	T-15	13.552	1195 x 821	110	72	1.818	No
	T-169	10.204	851 x 635	50	72	4.0	No

Table 3.4 Film Characteristics

Event	Camera Station	EG&G Film No.	Film Type	Measured Film Speed of Data Record (fr/sec)	Processing Rate (ft/min)	Processing Developer Type	Processing Temperature (^oF)	Remarks
B-20	T-9	60928	DXN	0.044mm/sec	70	D-76	90	Good Record (Streak Camera)
	T-12	60929	Anscochrome FPC	1469	-	ANSCO	-	Good Record (Color)
	T-15	60930	Cronar 140	1254	70	D-76	-	Poor Resolution
	T-169	60931	Cronar 140	-	70	D-76	-	Test - Slow Frame Rate
	T-199	60932	DXN	1055	70	D-76	90	Poor Contrast
B-20A	T-9	60933	DXN	0.0446mm/sec	70	D-76	90	Good Record (Streak Camera)
	T-12	60934	Anscochrome FPC	1989	-	ANSCO	-	Good Record (Color)
	T-15	60935	Cronar 140	-	70	D-76	90	Poor Resolution
	T-163	60936	Cronar 140	2568	70	D-76	90	Good Record
	T-197	60937	DXN	-	70	D-76	90	Fair (Poor Resolution)
	T-199	60938	DXN	1599	70	D-76	90	(Over Exposed)
B-24A	T-12	60939	Anscochrome	-	-	ANSCO	-	Late Detonation - No Fireball
	T-15	60940	Cronar 140	118.1	70	D-76	90	Fair - Slow Frame Rate
	T-169	60941	Cronar 140	-	70	D-76	90	Fair - Very Slow Frame Rate

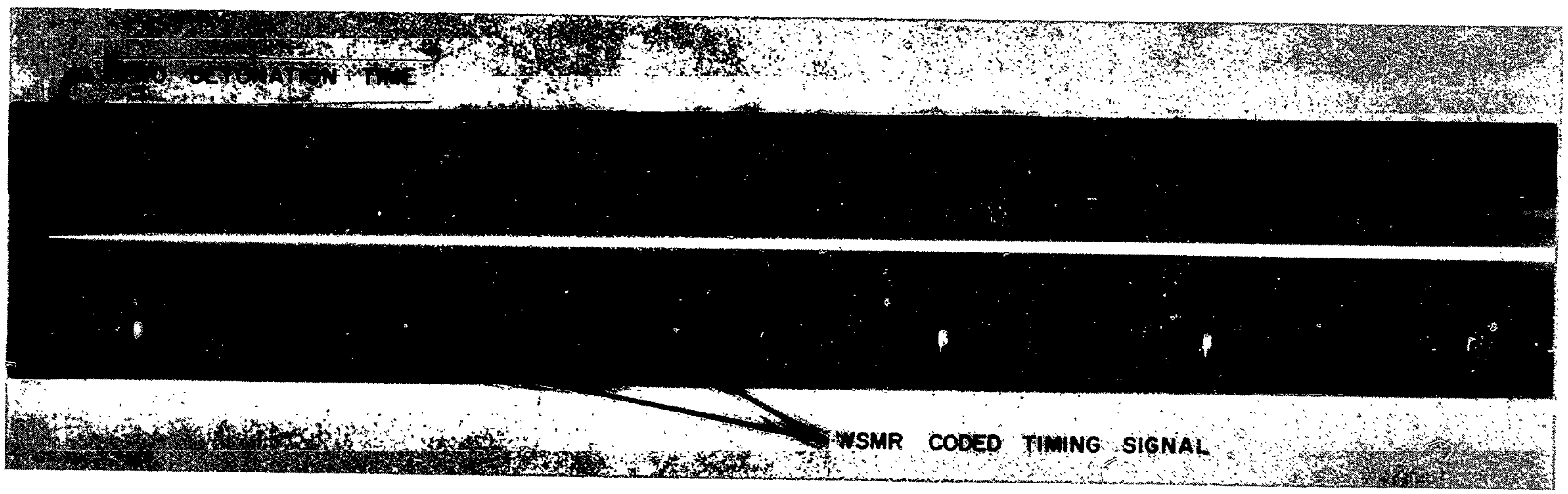
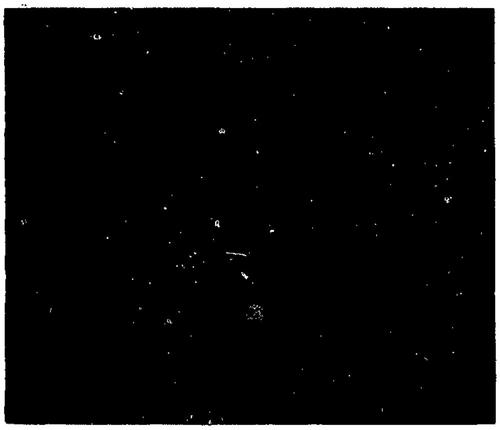
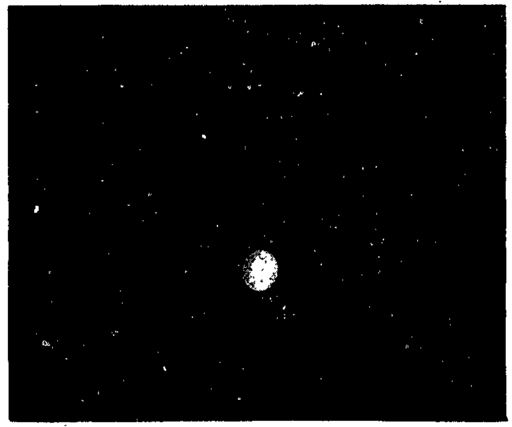


Figure 3.1 Streak Camera Record, B-20 Event, Station T-9

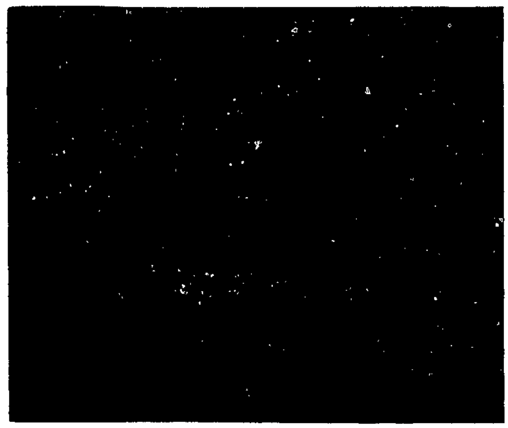


Frame 1 t ≈ 0 msec



Frame 2 t ≈ 0. 5 msec

Frame 5 t ≈ 6. 0 msec

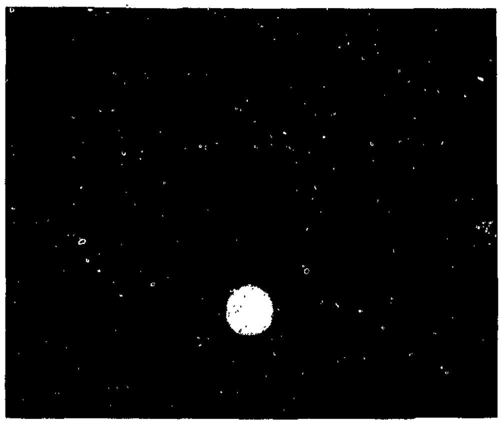


Frame 6 t ≈ 8. 5 msec

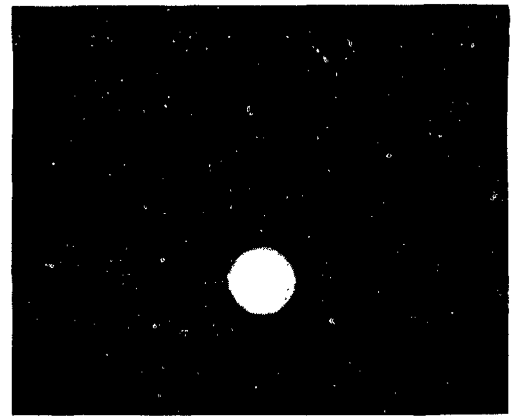
Frame 9 t ≈ 23 msec

Frame 10 t ≈ 38 msec

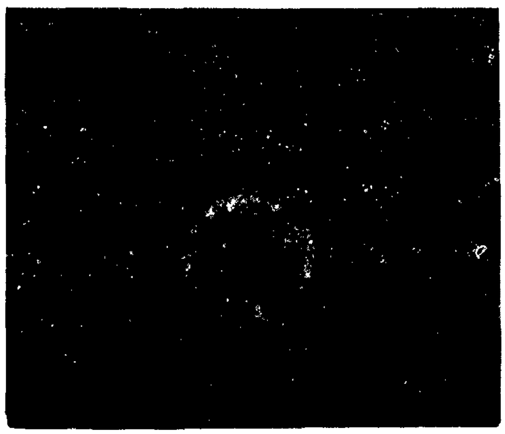
Figure 3. 2A Typical Photographic Record, BANSHEE 1962, Event B-20A, Station T-12



Frame 3 t ≈ 1.0 msec



Frame 4 t ≈ 2.0 msec



Frame 7 t ≈ 11 msec

Frame 8 t ≈ 16 msec

Frame 11 t ≈ 42 msec

Frame 12 t ≈ 50 msec

Figure 3.2B Typical Photographic Record, BANSHEE 1962, Event B-20A, Station T-12

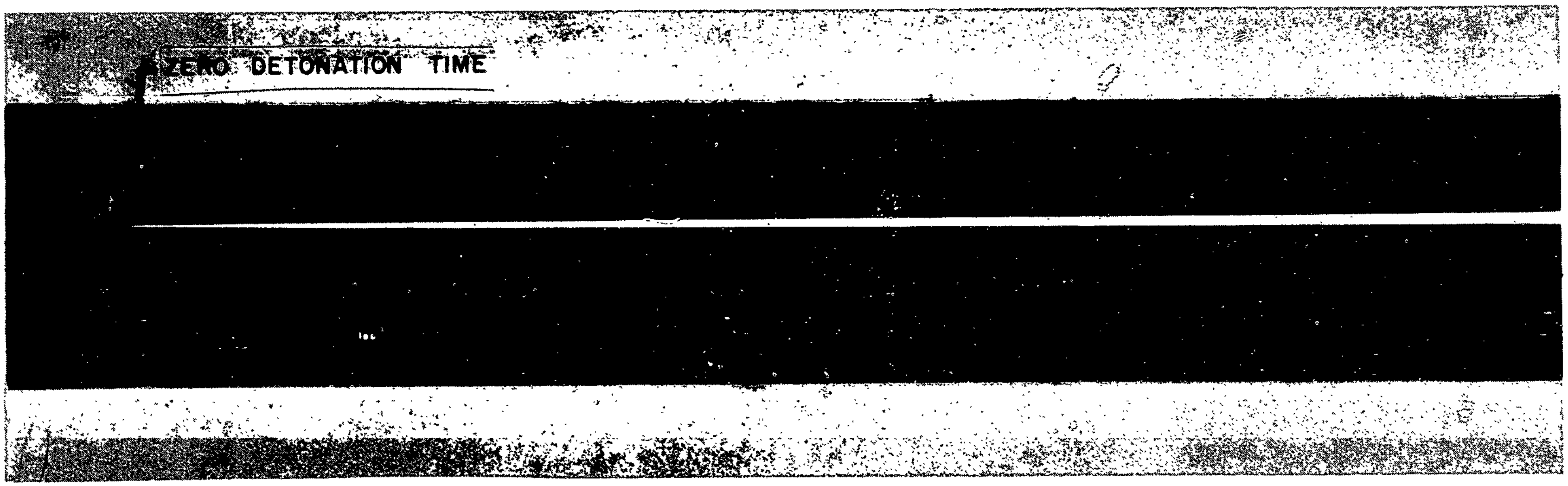


Figure 3.3 Streak Camera Record, B-20A Event, Station T-9

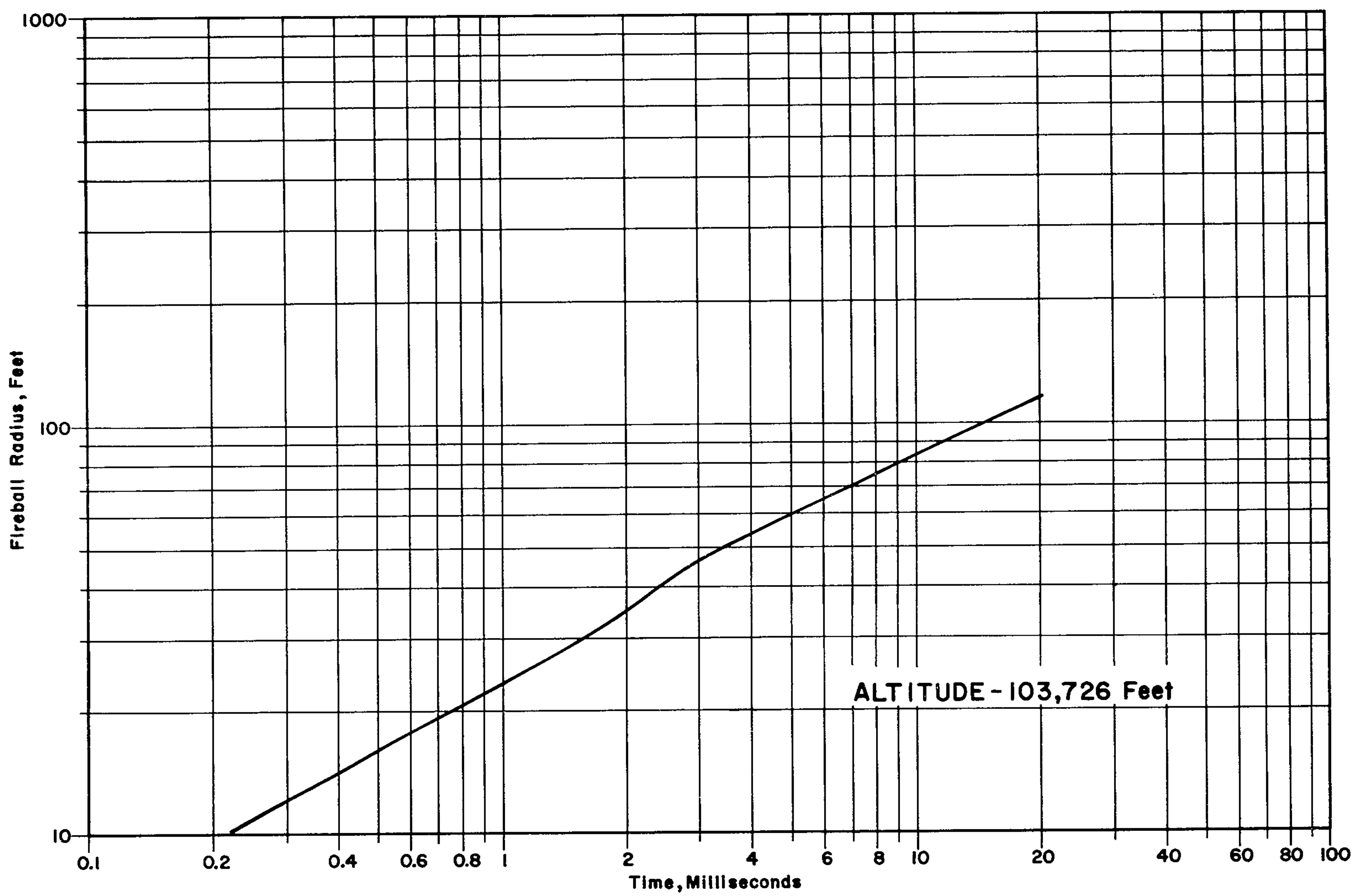


Figure 3.4 Fireball Radius vs Time, BANSHEE B-20 Event, Station T-9, Streak - 144.5 ft/sec

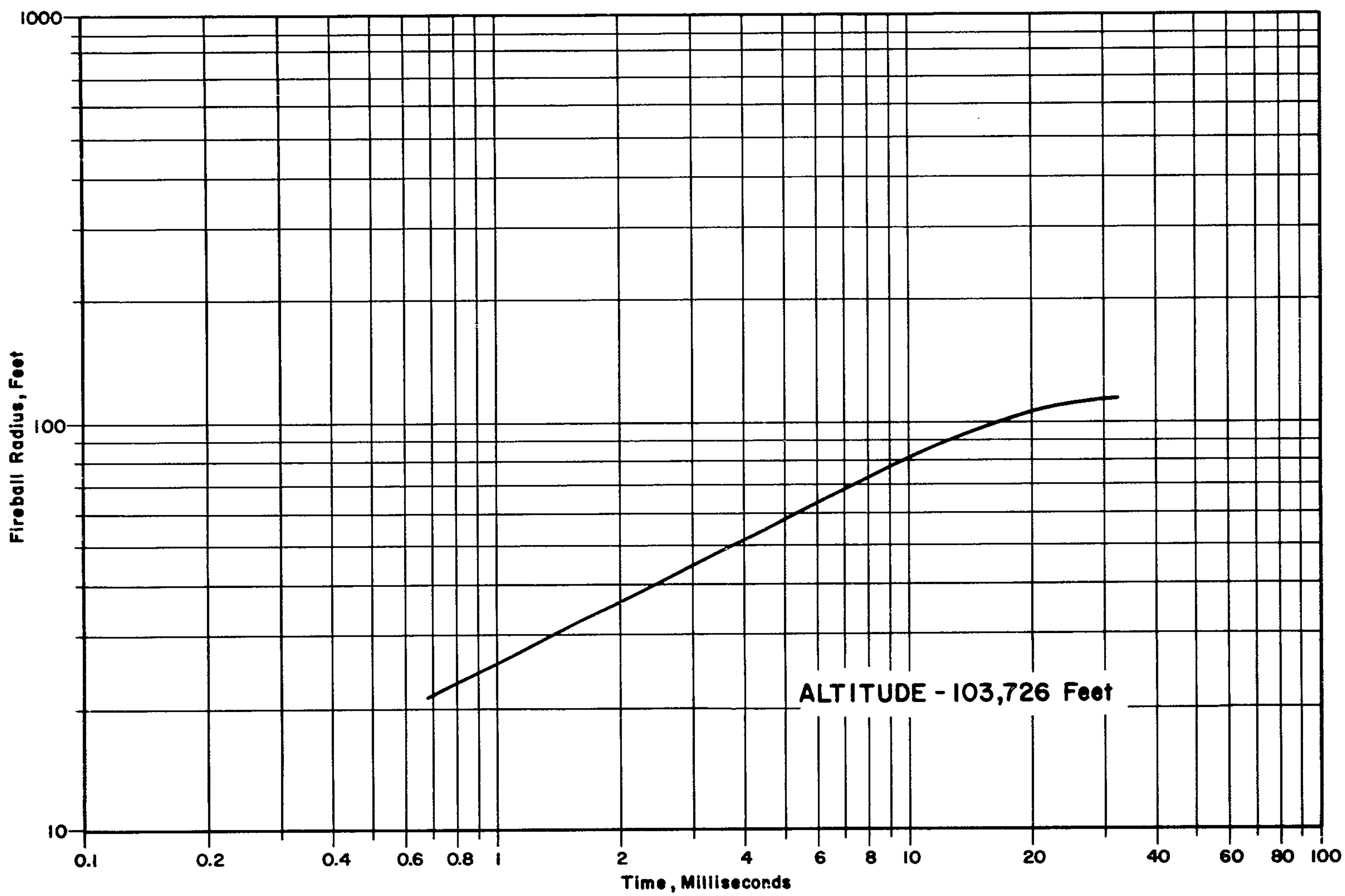


Figure 3. 5 Fireball Radius vs Time, BANSHEE B-20 Event, Station T-12, 1470 frames/sec

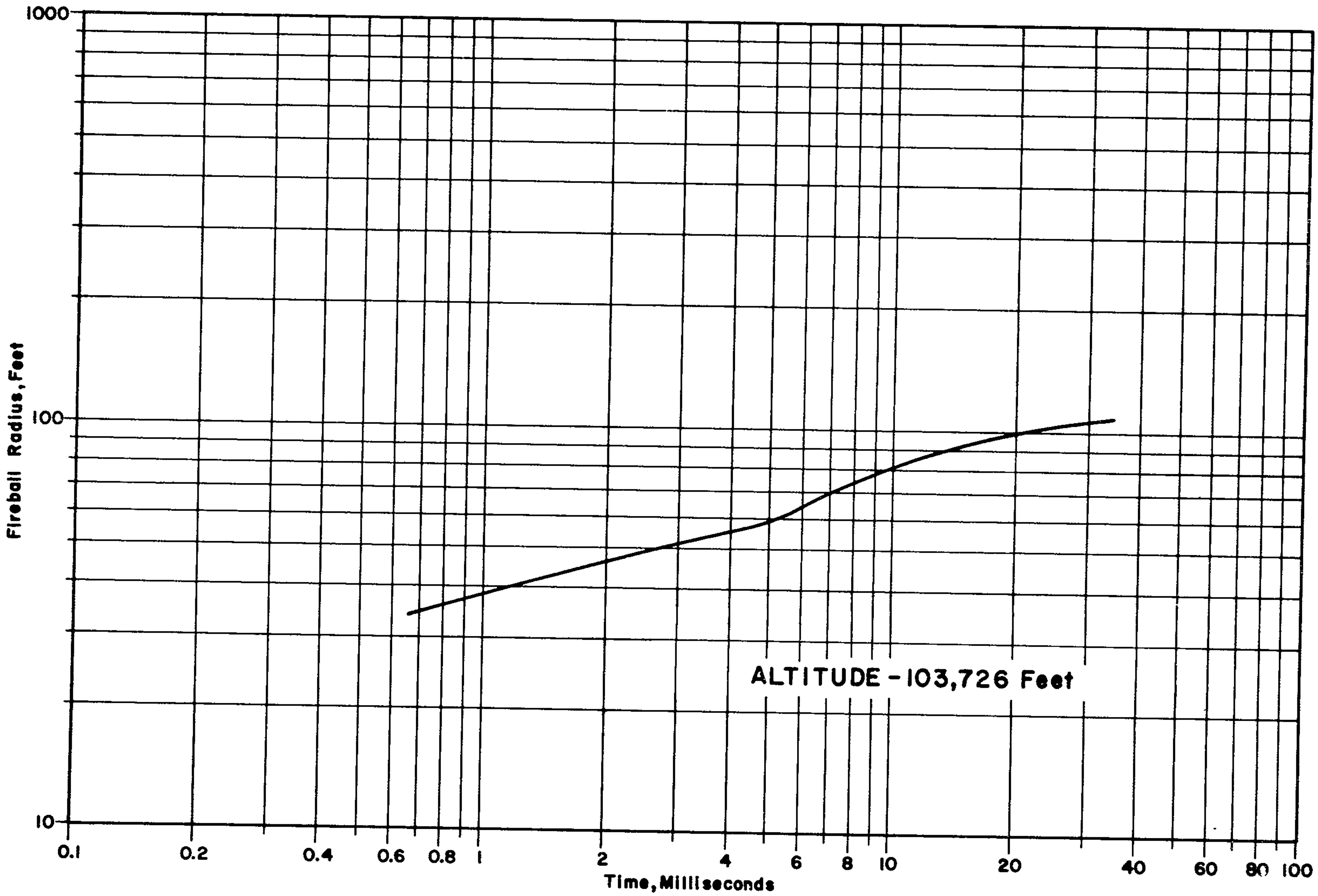


Figure 3.6 Fireball Radius vs Time, BANSHEE B-20 Event, Station T-12, 1255 frames/sec

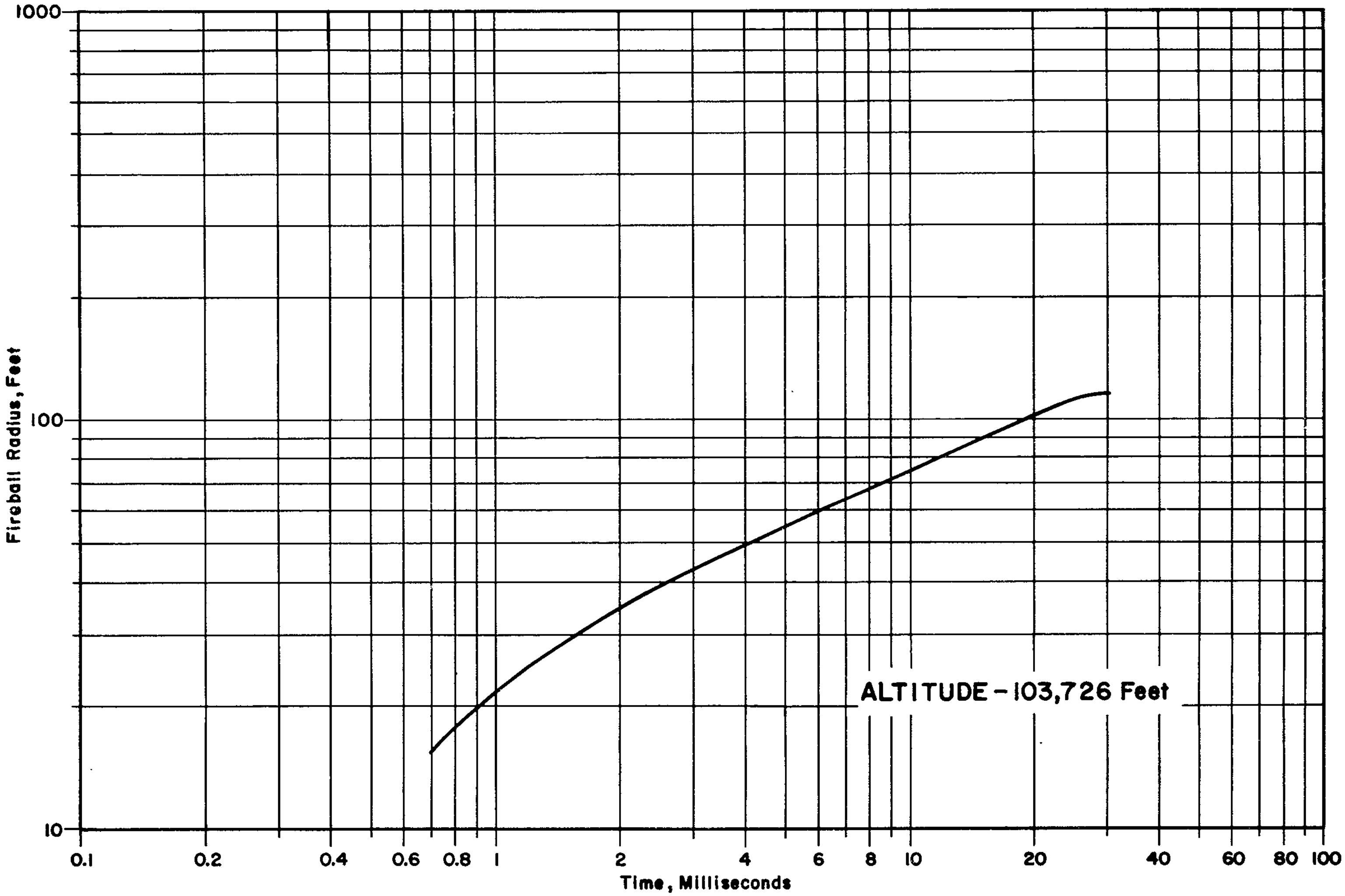


Figure 3.7 Fireball Radius vs Time, BANSHEE B-20 Event, Station T-199, 1055 frames/sec

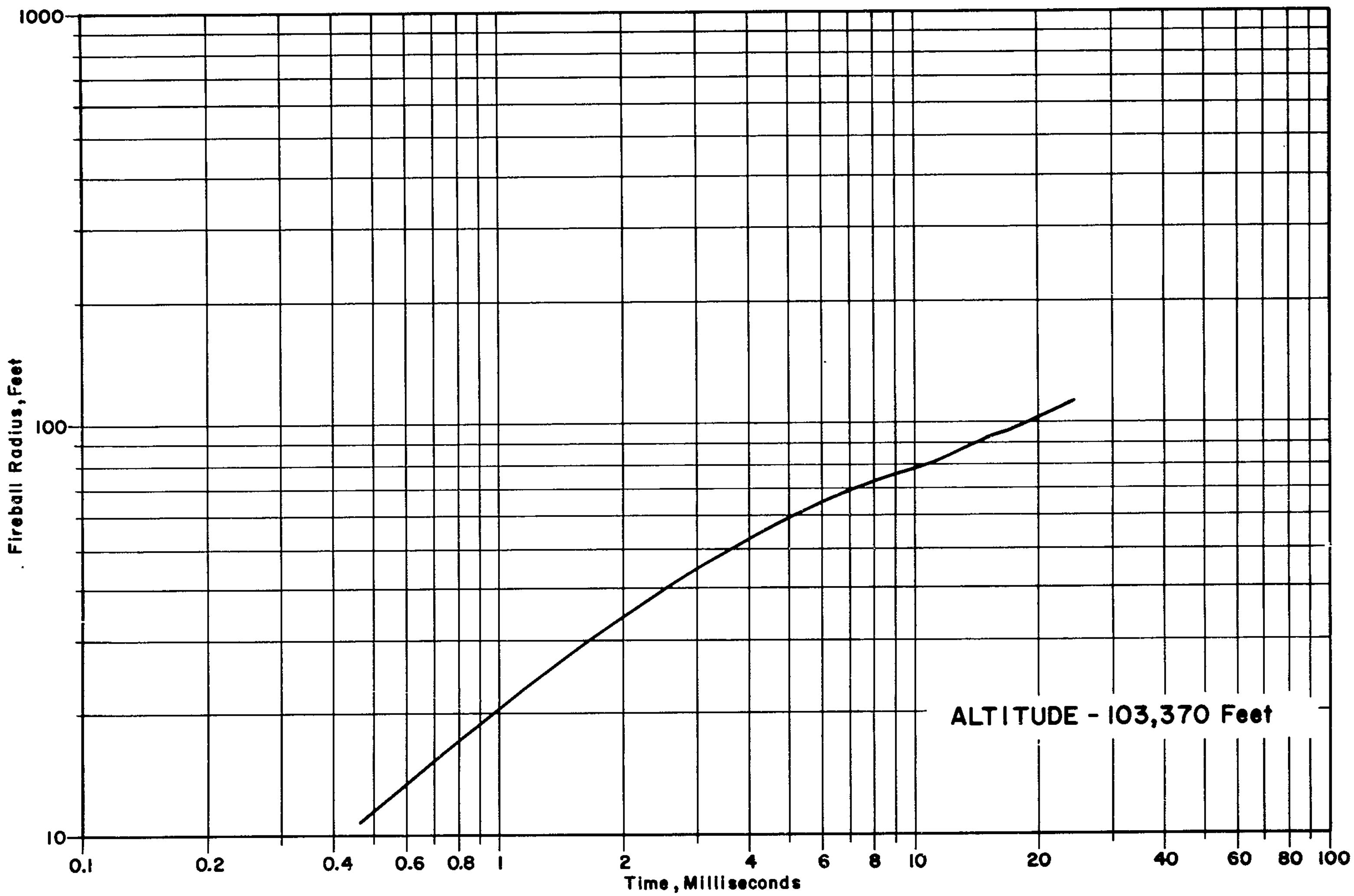


Figure 3.8 Fireball Radius vs Time, BANSHEE B-20A Event, Station T-9, Streak - 146.5 ft/sec

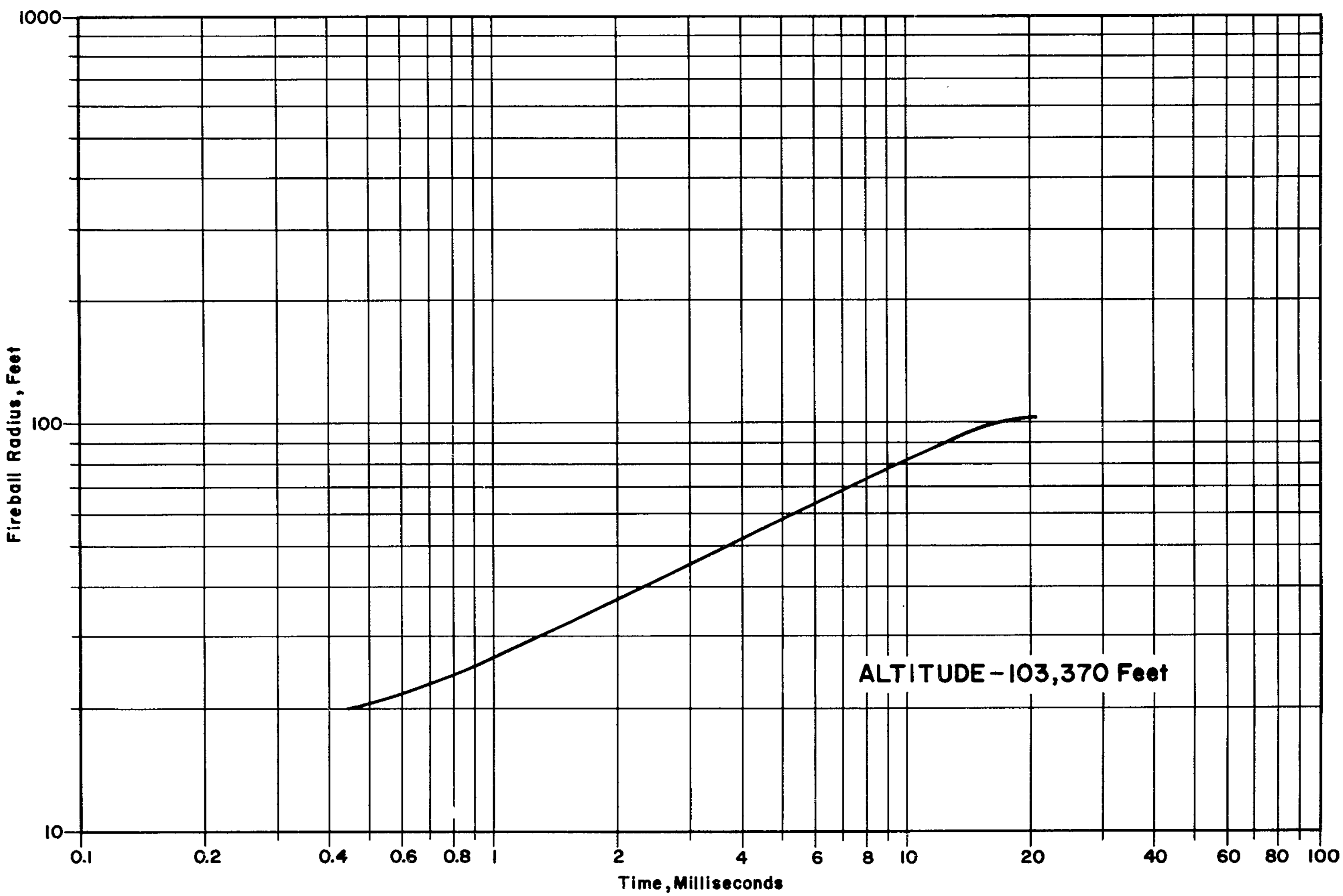


Figure 3. 9 Fireball Radius vs Time, BANSHEE B-20A Event, Station T-12, 1990 frames/sec

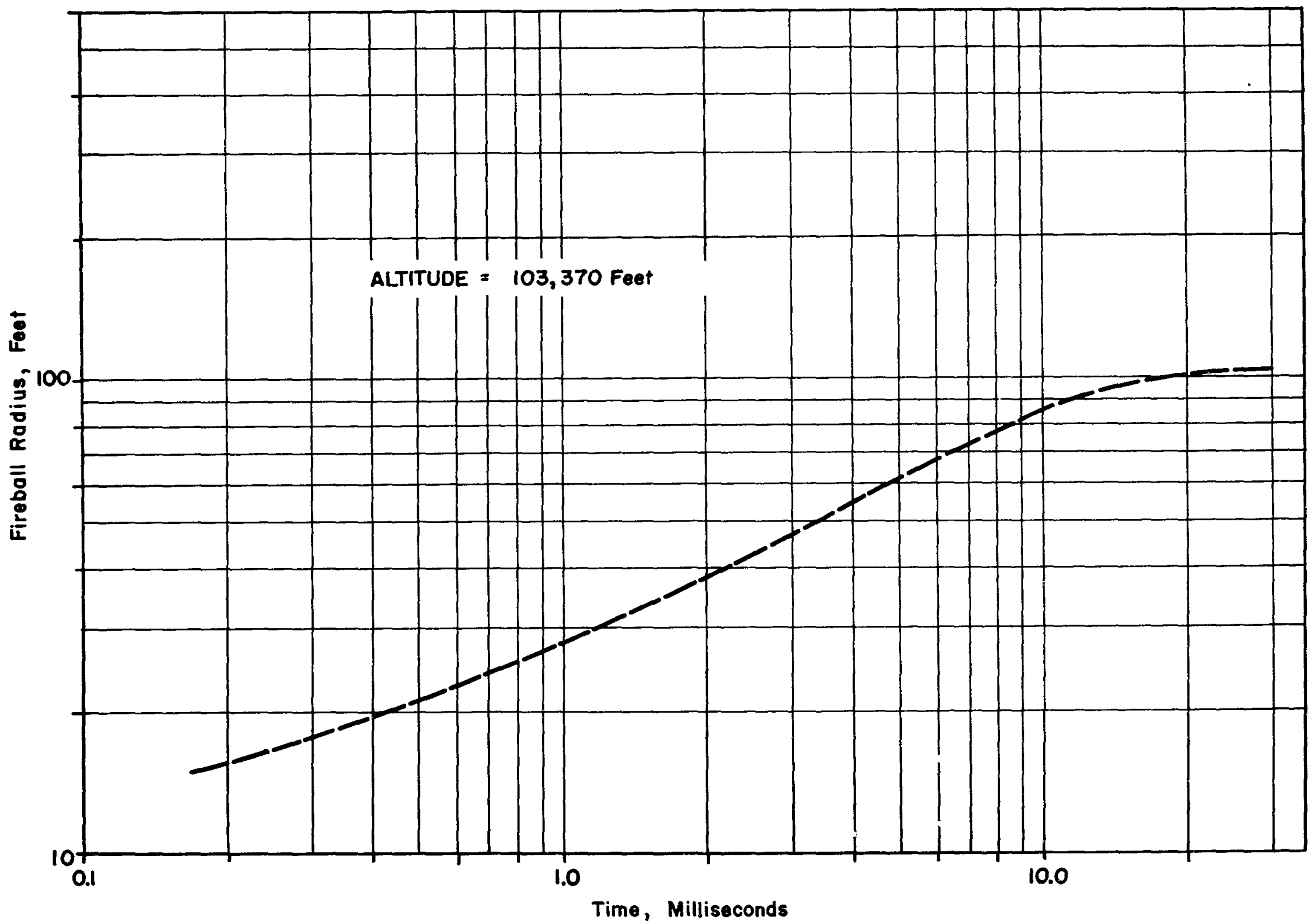


Figure 3.10 Fireball Radius vs Time, BANSHEE B-20A Event, Station T-163, 2568 frames/sec

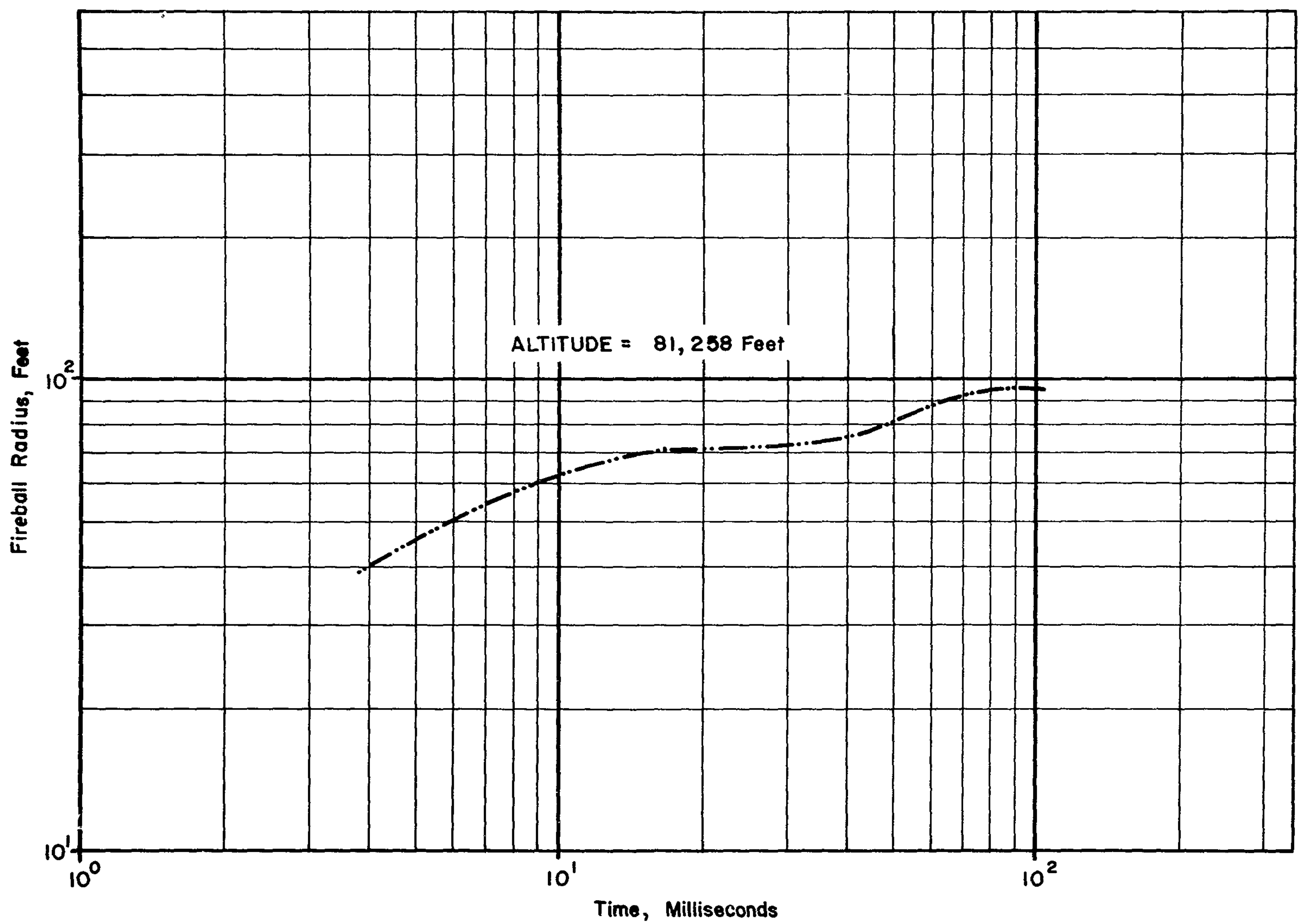


Figure 3.11 Fireball Radius vs Time, BANSHEE B-24A, Station T-15, 115 frames/sec

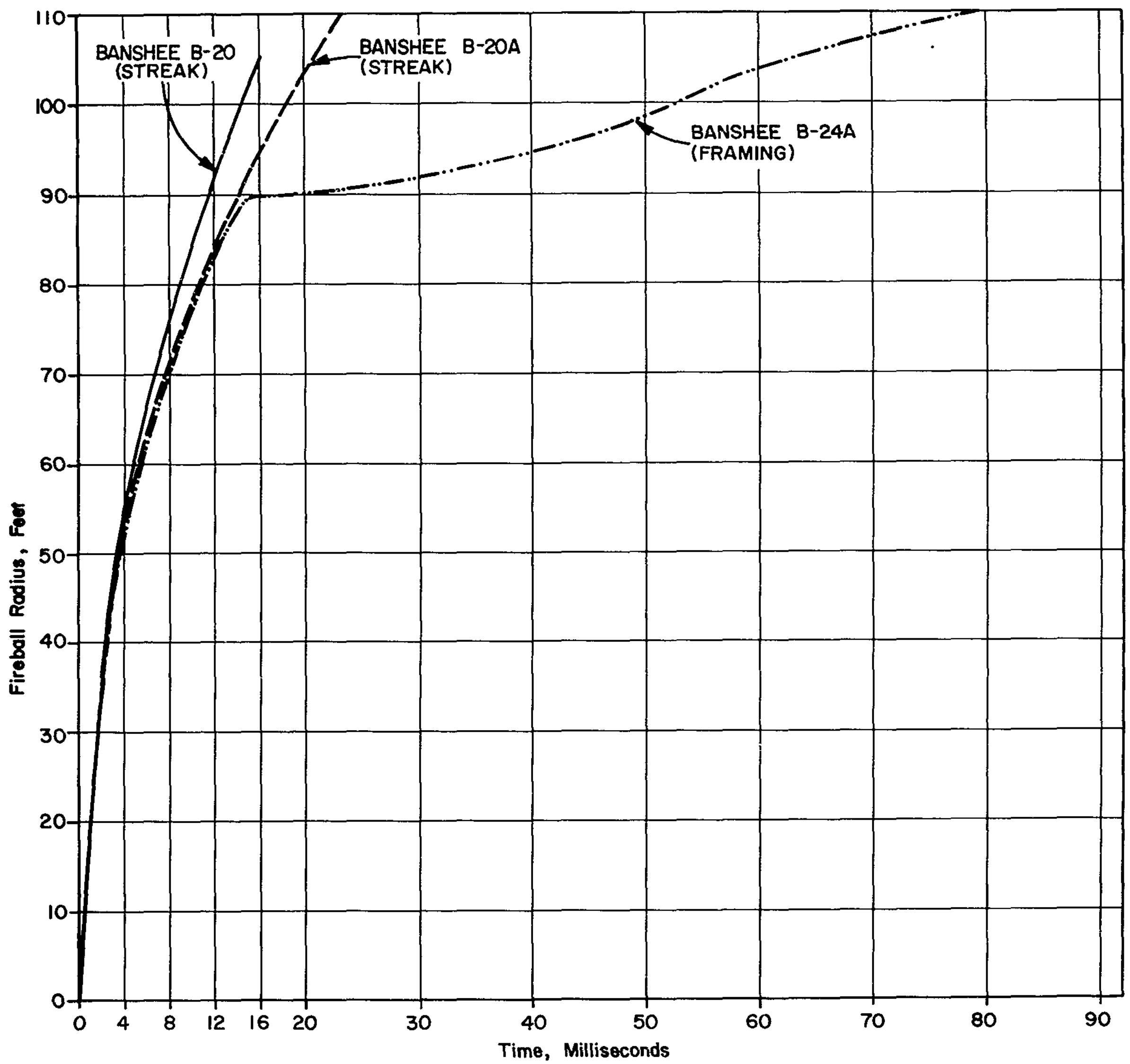


Figure 3.12 Linear Plot of Fireball Radius vs Time for 1962 BANSHEE Events

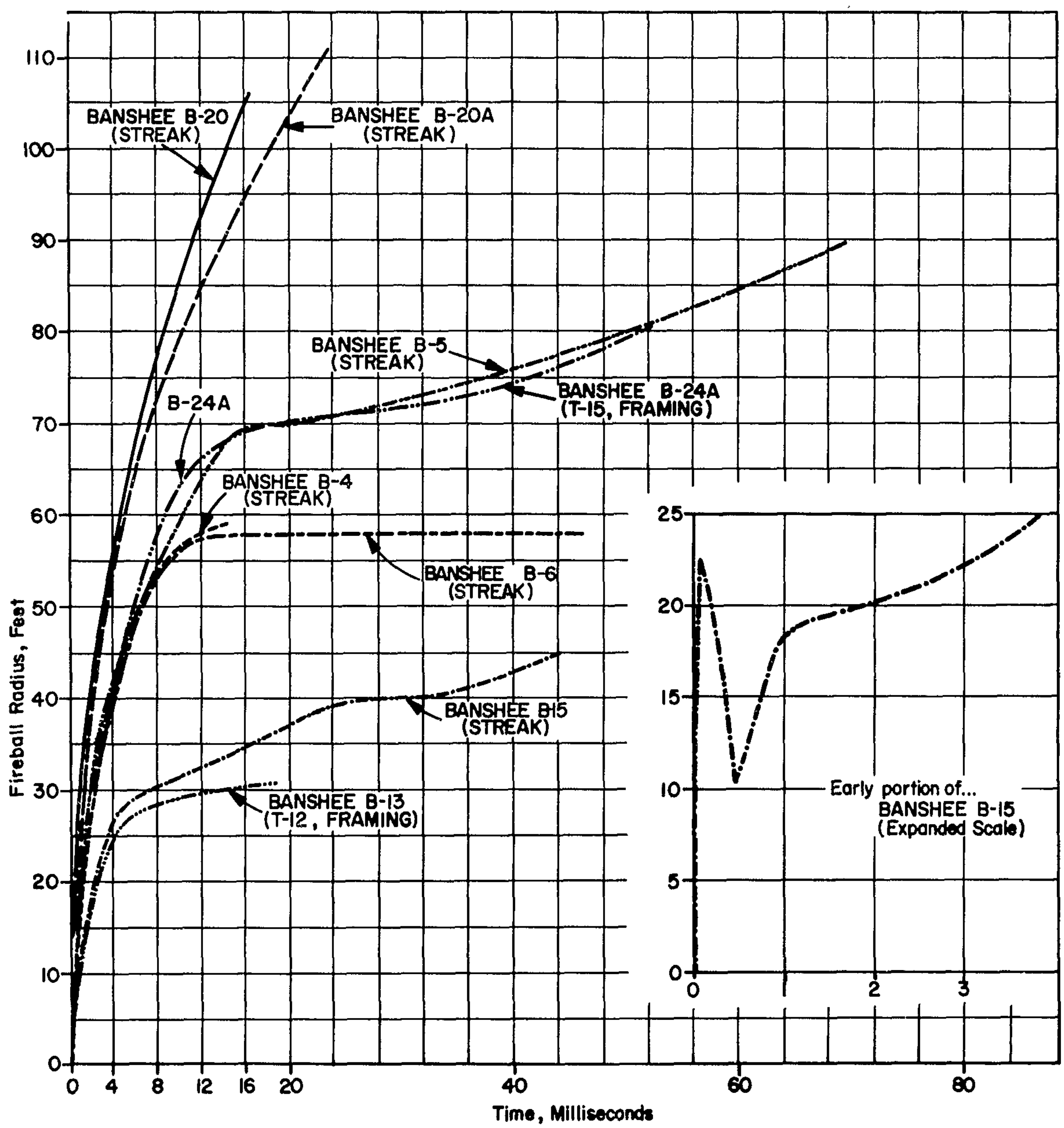


Figure 3.13 Linear Plot of Fireball Radius vs Time for 1961 and 1962 BANSHEE Events

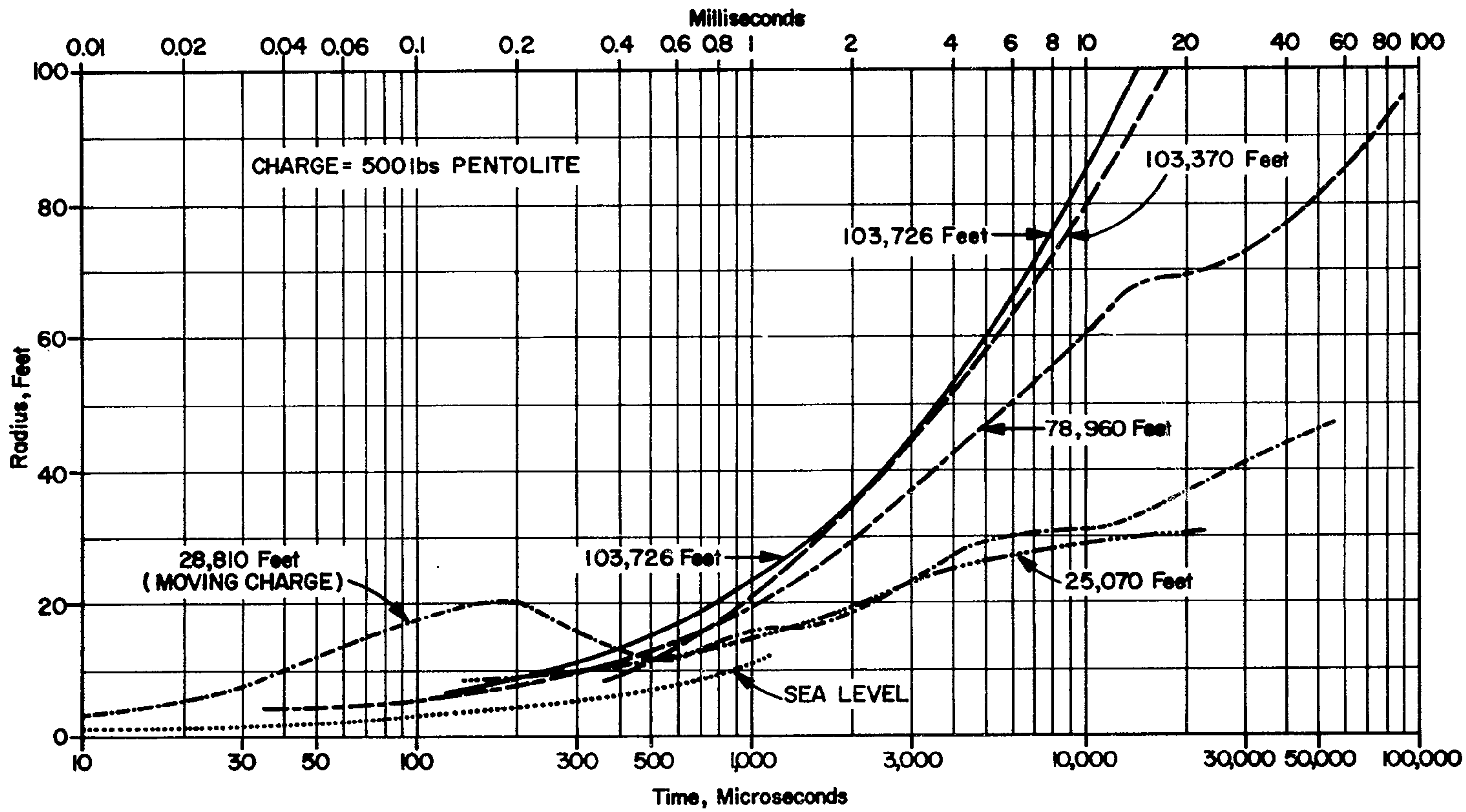


Figure 3. 14 Fireball Radius vs Time for Various Altitudes of Detonation, 1961 and 1962 BANSHEE Events

CHAPTER 4

ANALYSIS OF DATA AND CONCLUSIONS

As in the case of the 1961 events, all of the 1962 BANSHEE charges consisted of 500 pounds of pentolite. This standardization of the charge weight facilitates evaluating the scaling laws of explosion hydrodynamics as a function of altitude.

Figure 4. 1 is a plot of the scaled variables, reduced radius λ versus reduced time τ, as used by Brode (Reference 2). The data points from which these curves were constructed are shown on the curves. These curves are super-imposed on the 1961 λ versus τ data in Figure 4. 2. Table 4. 1 summarizes the ambient pre-shock conditions assumed for the 1962 events, and used in the determination of the reduced variables.

These parameters are used in the following relationships for determining λ and τ:

$$\lambda = \frac{R}{\alpha} \equiv \text{Reduced radius, in feet atmos}^{1/3}\text{pounds}^{-1/3}$$

$$\tau = \frac{tC_0}{\alpha} \equiv \text{Reduced time, in feet atmos}^{1/3}\text{pounds}^{-1/3}$$

Where: $$\alpha^3 = \frac{W}{P_0}$$

W = Initial total energy, in pounds of pentolite,

P_0 = Ambient air pressure, in atmospheres,

R = Fireball radius at time t

and C_0 = Ambient sound velocity, in feet per second

In the application of reduced variables to the fireball data, it has been implicitly assumed that the boundary of the photographed debris defines the "contact surface". As such, this boundary is then subject to the same scaling laws used for the behaviour of shocks and the contact surface.

Agreement of the scaled data of Figure 4. 2 is generally good within the limits of measurement accuracy. However, it appears that the 1962 high altitude (B-20 and B-20A) λ and τ plots do not start to roll over at about $\tau = 0.2$, as in the case of the 1961 data. This might be explained as a departure from the scaling laws at these altitudes, and/or a change with altitude in the relationship between debris and "contact surface".

The one 1962 low altitude event (B-24A) is in good agreement with the 1961 data (at approximately the same altitude). The spread in the data of Figure 3. 13 for these events (B-4/B-6 and B-5/B-24A) is believed to be, primarily, the result of variations in the detonation characteristics of the charges.

The rebrightening phenomenon occurs about 35 milliseconds after detonation, see Figure 3. 2, and is not strongly observable on the streaked fireball image. Because of this deterioration of the data, the effect does not appear in the λ versus τ plots. Possible explanations of the rebrightening are; (1), the reduction of debris cloud opacity, permitting the inner-fireball emission to appear, or (2), restoration of the chemical reactions which, for some reason, did not go to completion in the original explosion.

Table 4.1 Ambient Pre-shock Conditions Assumed For The 1962 BANSHEE Events

Event	Altitude (feet)	C_0 (feet/sec)	P_0 (Atmos)
B-20	103,726	993.35	9.31×10^{-3}
B-20A	103,370	993.10	9.52×10^{-3}
B-24A	81,258	978.50	2.603×10^{-2}

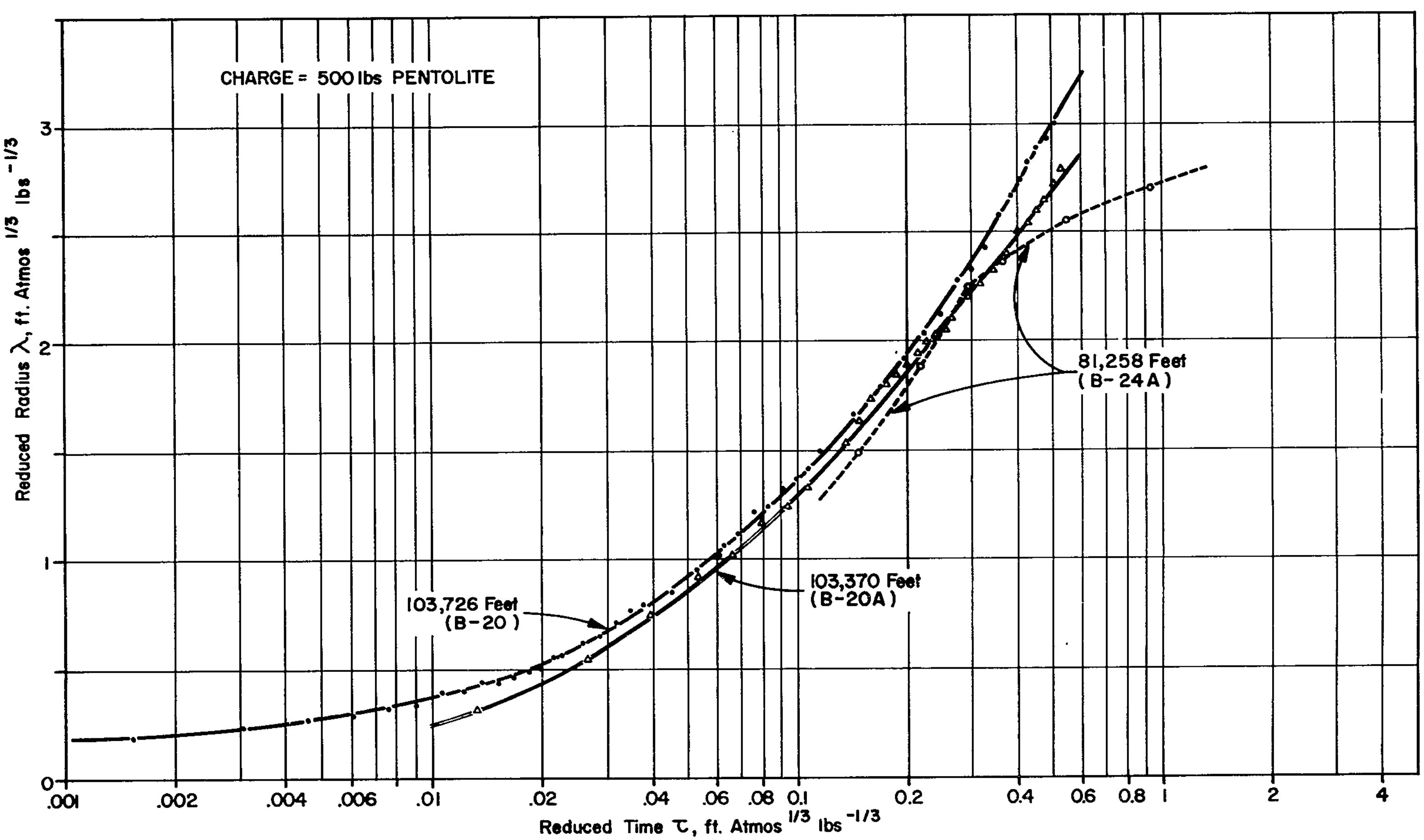


Figure 4.1 Reduced Radius vs Reduced Time, BANSHEE Events B-20, B-20A, and B-24A

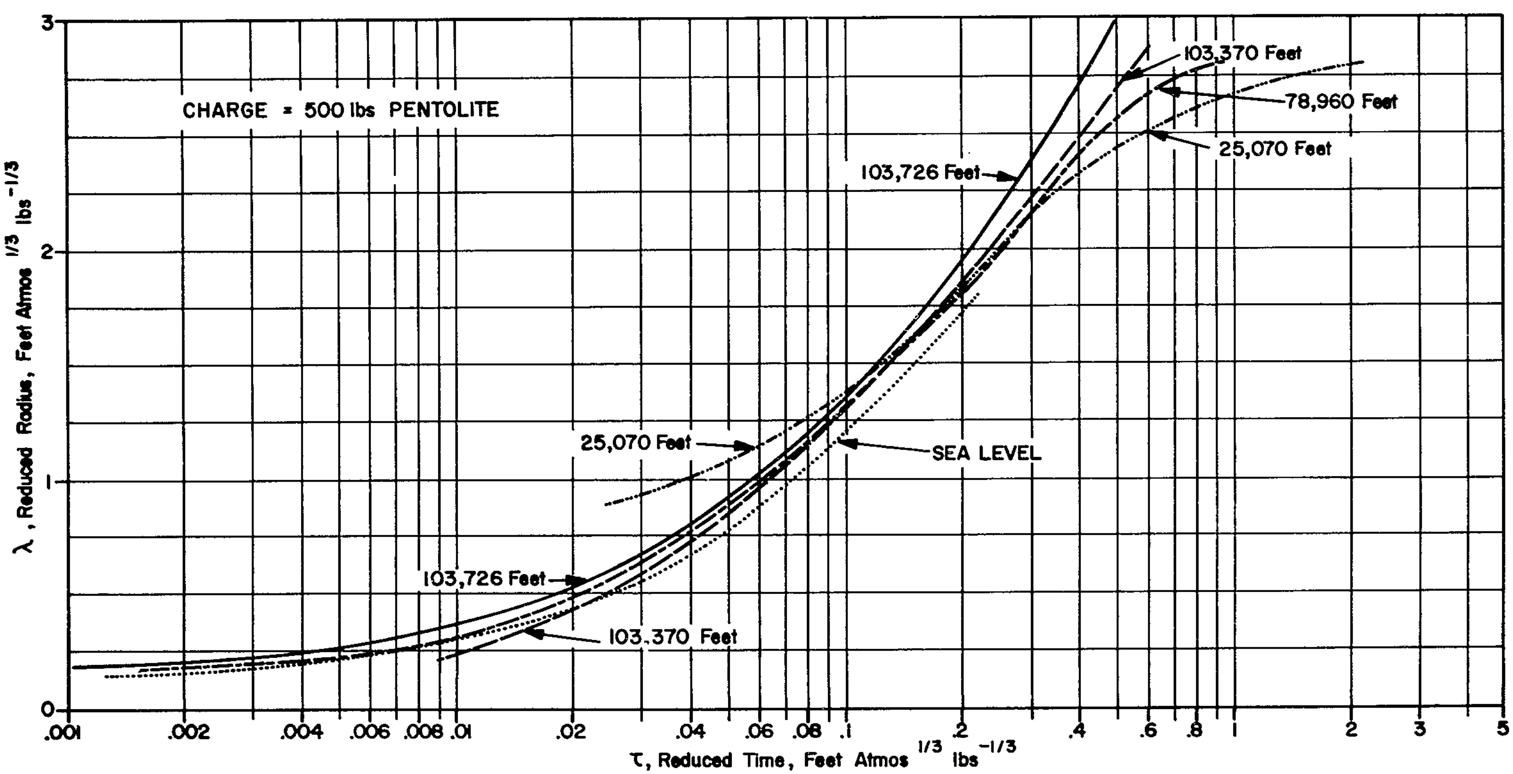


Figure 4. 2 Reduced Fireball Radius vs Reduced Time For Various Detonation Altitudes, 1961 and 1962 BANSHEE Events

REFERENCES

(1) Hansen, D. F., and McCue, J. C., "Photographic Measurements On BANSHEE," EG&G Report No. B-2596, May 28, 1963.

(2) Brode, H. L., "Blast Wave From A Spherical Charge," Physics of Fluids, 2, 2, 217-229 (March/April, 1959).

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